

Li-Ion Battery Technology Assessment for Future NASA Planetary Missions

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Outline

- **Potential NASA Applications**
 - **Planetary Mission Battery Requirements**
 - **Interagency Li-Ion Battery Program**
 - **Technology Assessment**
 - **Summary and Conclusions**
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Potential NASA Applications

Planetary Landers



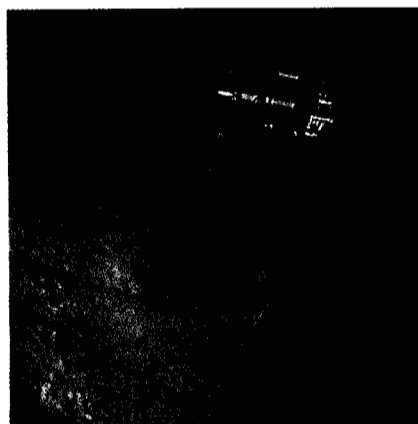
GEO Spacecraft



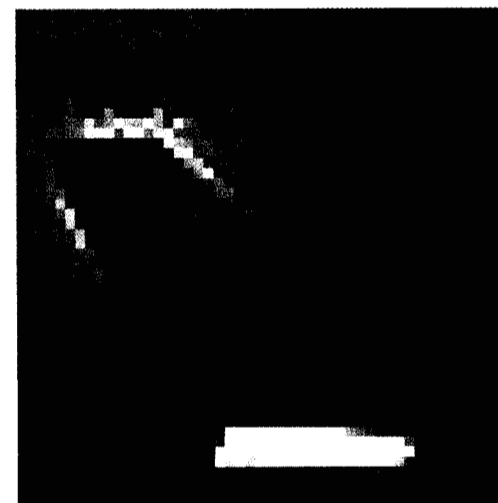
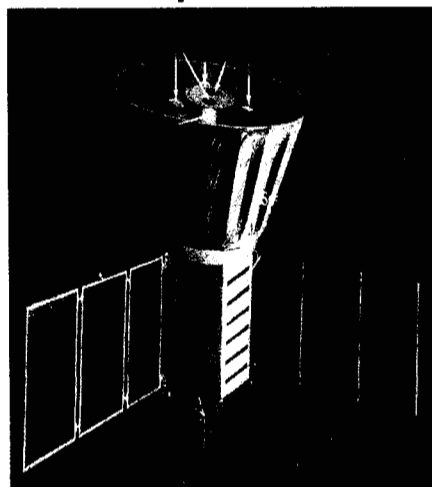
Astronaut Equipment



Europa Orbiter

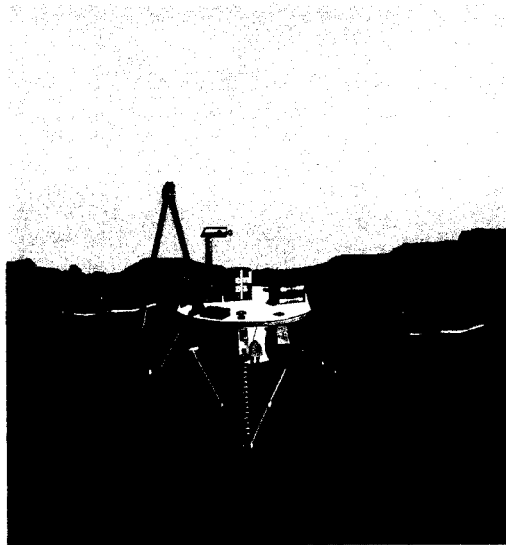


LEO Spacecraft





Mars 2003 Lander



Launch Date: Jan 2003

Flight Time: Nine Months

Mission Objectives

- Platform for instruments and technology experiments designed to provide key insights to decisions regarding human missions to Mars.
- In-situ demonstration test of rocket propellant production.
- Martian soil properties and surface radiation environment

Battery Requirements

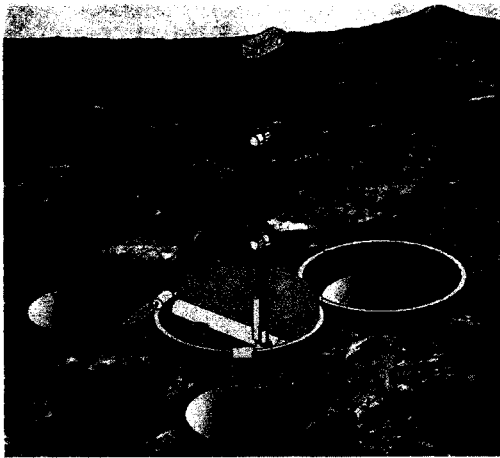
- Voltage: 24-32
- Capacity: 68 Ah
- Operating Temp.: -20-40 C
- Cycle Life: 300
- Calendar Life: Three years
- Sp. Energy: > 100 Wh/kg
- Energy Density: >240 Wh/l

Technology Challenges

- Battery Operation after Two years Active storage.
- Low Temperature Performance



Mars Scout Missions



Launch Date: Jan 2003
Flight Time: Nine Months
Mission Objectives

- **Lander robustness**

Battery Requirements

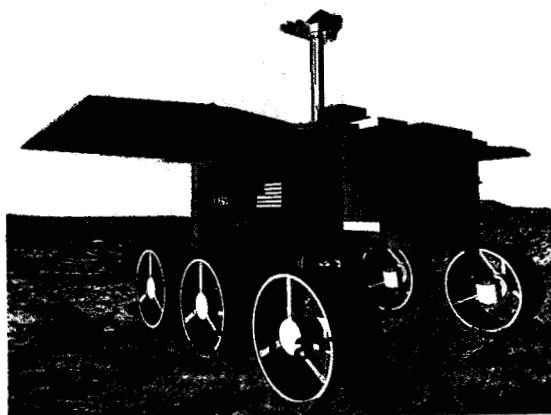
- **Voltage: 24-32**
- **Capacity: 6-8 Ah**
- **Cycle Life: 20-30 K, at 20-30% DoD**
- **Calendar Life: Five years**
- **Sp. Energy: > 100 Wh/kg**
- **Energy Density: >240 Wh**

Technology Challenges

- **Battery Operation after Two years**
Active storage
- **Low Temperature Performance**



Mars 2005 Lander/Rover



Launch Date: April 2005

Flight Time: Nine Months

Mission Objectives

- Platform for instruments and technology experiments designed to provide key insights to decisions regarding human missions to Mars.
- In-situ demonstration test of rocket propellant production.
- Martian soil properties and surface radiation environment

Battery Requirements

- Voltage: 24-32
- Capacity: 140 Ah
- Operating Temp.: -20-40 C
- Cycle Life: > 300
- Calendar Life: Three years
- Sp. Energy: > 100 Wh/kg
- Energy Density: >240 Wh/l

Technology Challenges

- Battery Operation after Two years Active storage
- Low Temperature Performance



Mars Microsats



Launch Date: Jan 2003
Flight Time: Nine Months

Mission Objectives

- **Developing a communications capability to provide a substantial increase in data rates and connectivity from Mars to Earth;**
- **Developing an in situ navigation capability to enable more precise targeting and location information on approach and at Mars.**

Battery Requirements

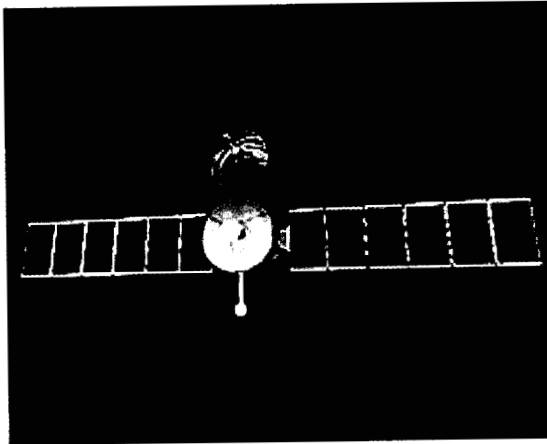
- **Voltage: 24-32**
- **Capacity: 6-8 Ah**
- **Cycle Life: 20-30 K, at 20-30% DoD**
- **Calendar Life: Five years**
- **Sp. Energy: > 100 Wh/kg**
- **Energy Density: >240 Wh/l**

Technology Challenges

- **Long Cycle Life**
- **Low Temperature Performance**



Mars Sats



Launch Date: Jan 2003
Flight Time: Nine Months

Mission Objectives

- Developing a communications capability to provide a substantial increase in data rates and connectivity from Mars to Earth.
- Developing an in situ navigation capability to enable more precise targeting and location information on approach and at Mars.

Battery Requirements

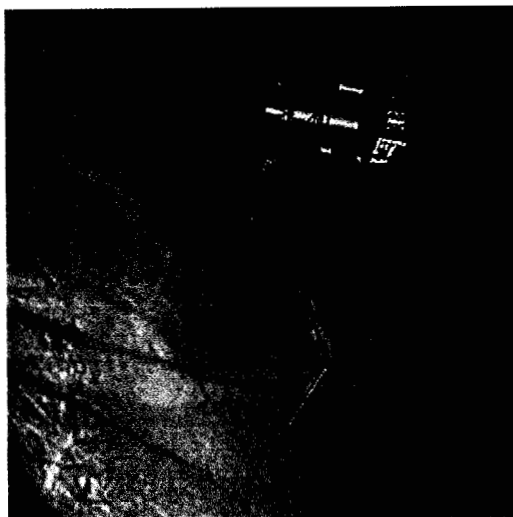
- Voltage: 24-32
- Capacity: 20 -35 Ah
- Cycle Life: 20-30 K, at 20-30% DoD
- Calendar Life: 7-9 years
- Sp. Energy:> 100 Wh/kg
- Energy Density: >240 Wh/l

Technology Challenges

- Long Cycle Life
- Low Temperature Performance



Europa Orbiter



Launch Date: January 2006

Flight Time: 6-8 Years

Mission Objectives

- **Determine the presence or absence of a subsurface ocean**
- **Characterize the three-dimensional distribution of any subsurface liquid water and its overlying ice layers**
- **Understand the formation of surface features, including sites of recent or current activity, and identify candidate landing sites for future lander missions.**

Battery Requirements

- **Voltage: 24-32**
- **Capacity: 6-8 Ah**
- **Cycle Life: < 400**
- **Calendar Life: 6-8 Years**
- **Sp. Energy:> 100 Wh/kg**
- **Energy Density: >240 Wh/l**

Technology Challenges

- **Long Calendar Life**
- **Radiation Tolerance**



Solar Probe



Launch Date: 2007

Flight Time: 3.8 - 1st Perihelion ;4.5 - 2nd Perihelion

Mission Objectives

- **Determine the acceleration processes and find the source regions of the fast and slow solar wind at maximum and minimum solar activity.**
- **Locate the source and trace the flow of energy that heats the corona;**
- **Construct the 3-d density configuration from pole to pole, and determine the subsurface flow pattern, the structure of the polar magnetic field and its relationship with the overlying corona.**

Battery Requirements

- **Voltage: 24-32**
- **Capacity: 6-8 Ah**
- **Cycle Life: < 400**
- **Calendar Life: 5-7 Years**
- **Sp. Energy:> 100 Wh/kg**
- **Energy Density: >240 Wh/l**

Technology Challenges

- **Long Calendar Life**



Interagency Li-Ion Battery Program



Objectives

- **Develop aerospace quality, high energy density and long life lithium-ion cells and batteries**
- **Establish U.S. production sources**
- **Demonstrate technology readiness**
 - **Rovers and Landers by 2000**
 - **Aviation / UAV's by 2001**
 - **DOD terrestrial applications by 2001**
 - **GEO missions by 2002**
 - **LEO missions by 2004**



Interagency Li-Ion Battery Program Performance Targets

	LANDERS	ROVERS	GEO ORBITER	LEO/PLA> ORBITER	AIRCRAFT	UAV
CAPACITY, Ah	30	8	10, 20, 35	10, 20, 35	5-20	100-200
VOLATAGE (v)	28	28	28-100	28	28-270	28-100
DISCH. RATE	C/5-C	C/5-C/2	C/2	C/2-C	C	C/5-C
CYCLE LIFE @DOD (%)	>500 >60%	>500 >60%	>2000 >75%	>30,000 >30%	>1000 >50%	>1000 >50%
OPERATING TEMP, °C	-40 to 40	-40 to 40	-5 to 30	-5 to 30	-40 to 65	-40 to 65
Calendar Life	3	3	>10	>5	>5	>5
SP. ENERGY (Wh/Kg)*	> 100	> 100	> 100	> 100	> 100	100
ENRGY DENSITY (Wh/l)*	120-160	120-160	120-160	120-160	120-160	120-160

Based on 100%DOD at BOL



Li-Ion Battery Technology Assessment



Li-Ion Battery Technology Assessment



Objectives

- **Assess viability of using lithium-ion technology for future NASA applications.**
- **Demonstrate technology readiness for near term planetary missions.**
 - **Mars Landers**
 - **Mars Rovers**
 - **Mars Micro Sats**
 - **Outer Planetary Missions**



Li-Ion Battery Technology Assessment Test Plan Outline

•Electrical Performance Characterization

Range of charge and discharge rates (C/2, C/3.3, C/5 and C/10)

Range of temperatures (-30, -20, 0, 23, 40°C)

Pulse capability (40 and 60A)

Impedance measurements

•Cycle Life Performance

Room temperature cycle life (23° +/- 2°C)

Low temperature cycle life (-20°C)

High temperature cycling (40°C)

Variable temperature cycling

• Storage Characteristics

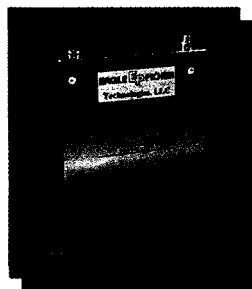
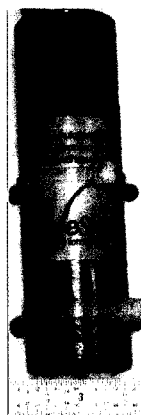
*** 2 Month storage test (0 and 40°C, 50 and 100% SOC)**

*** Accelerated storage test: at different SOC (50, 70,100% SOC),
temperatures (25, 40, 55°C), and storage conditions.**

• Mission Simulation Testing



Li-Ion Battery Technology Assessment Test Cells

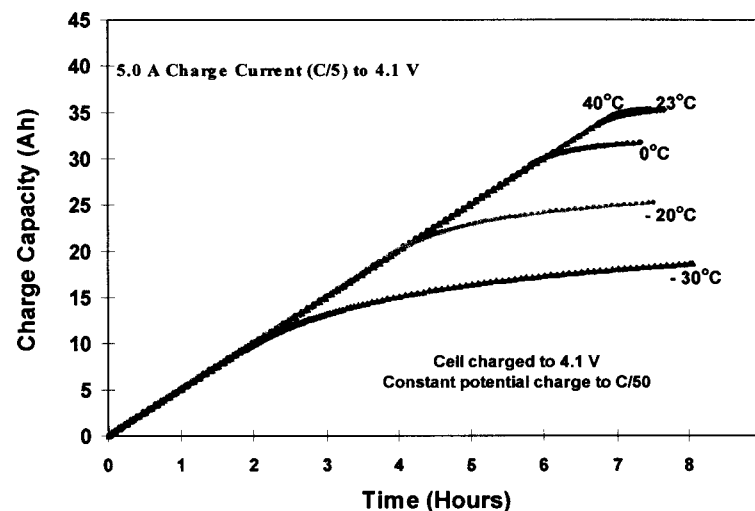
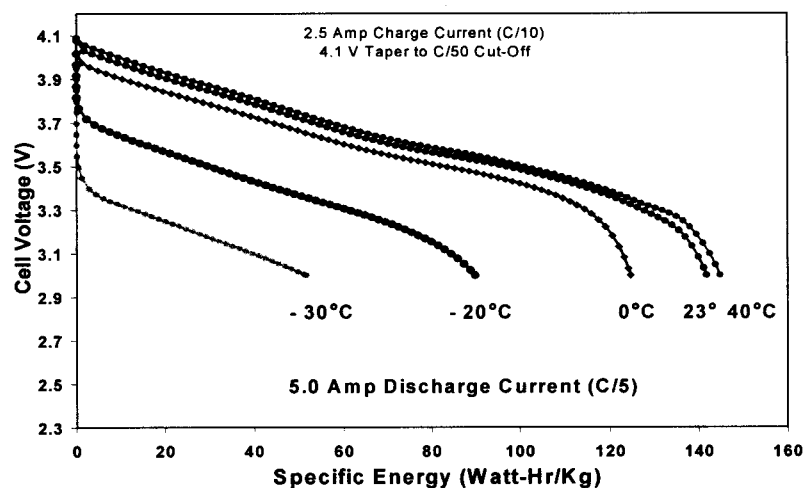


- **Yardney**
 - **Baseline 5 Ah Cells**
 - **First generation 20 Ah Cells for Mars Lander**
 - **Second generation 20/25 Ah cells for Mars Lander**
 - **First generation 8Ah Cells for Rover**
 - **MSP 01 25/35 Cells**
- **BlueStar**
 - **Baseline 20 Ah Cells**
 - **First Generation 25 Ah Cells for Mars Lander**
 - **Second generation 25/35 Ah Cells for Mars Lander**
 - **First Generation Rover Cells (6-8 Ah)**
- **Eagle Picher**
 - **Baseline 15/20 Ah cells**
 - **First Generation 50 Ah Cells-Aircraft**
- **SAFT**
 - **Baseline D cells**
 - **First Generation Rover Cells (8-9 Ah)**
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Li-Ion Battery Technology Assessment

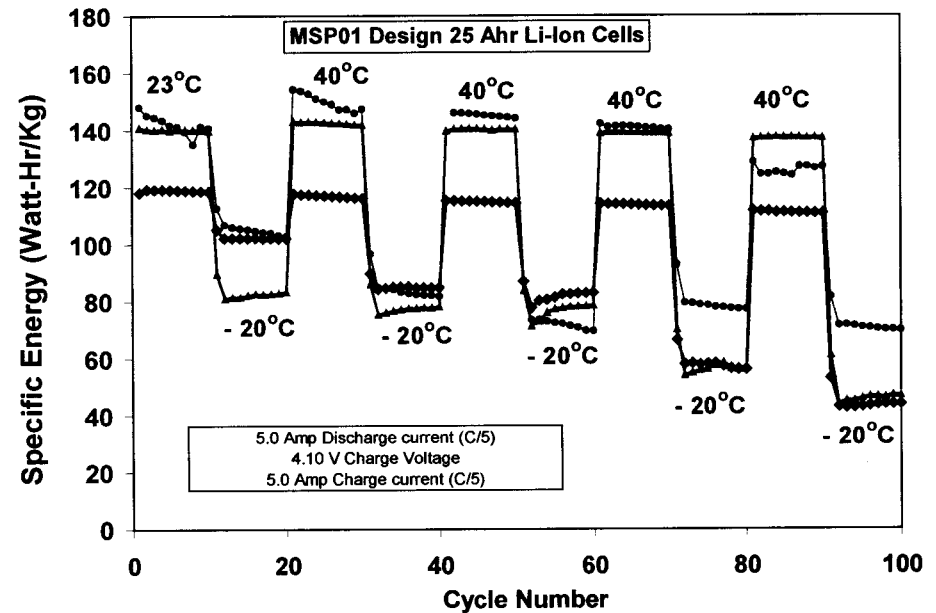
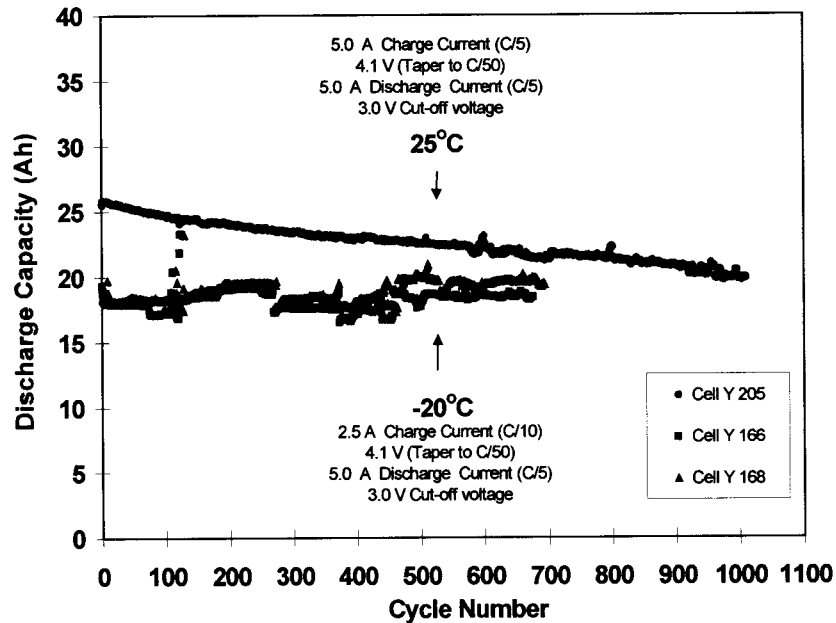
Electrical Characterization Studies



- Cells were found to deliver > 140 Wh/kg at RT
- Cells were found to deliver about 100 Wh/kg at -20C
- Cells can accept charge at -20C
- Similar performance capability observed with both 8 and 25 Ah cells
- Cell from all vendors showed similar capabilities



Li-Ion Battery Technology Assessment Cycle Life Studies

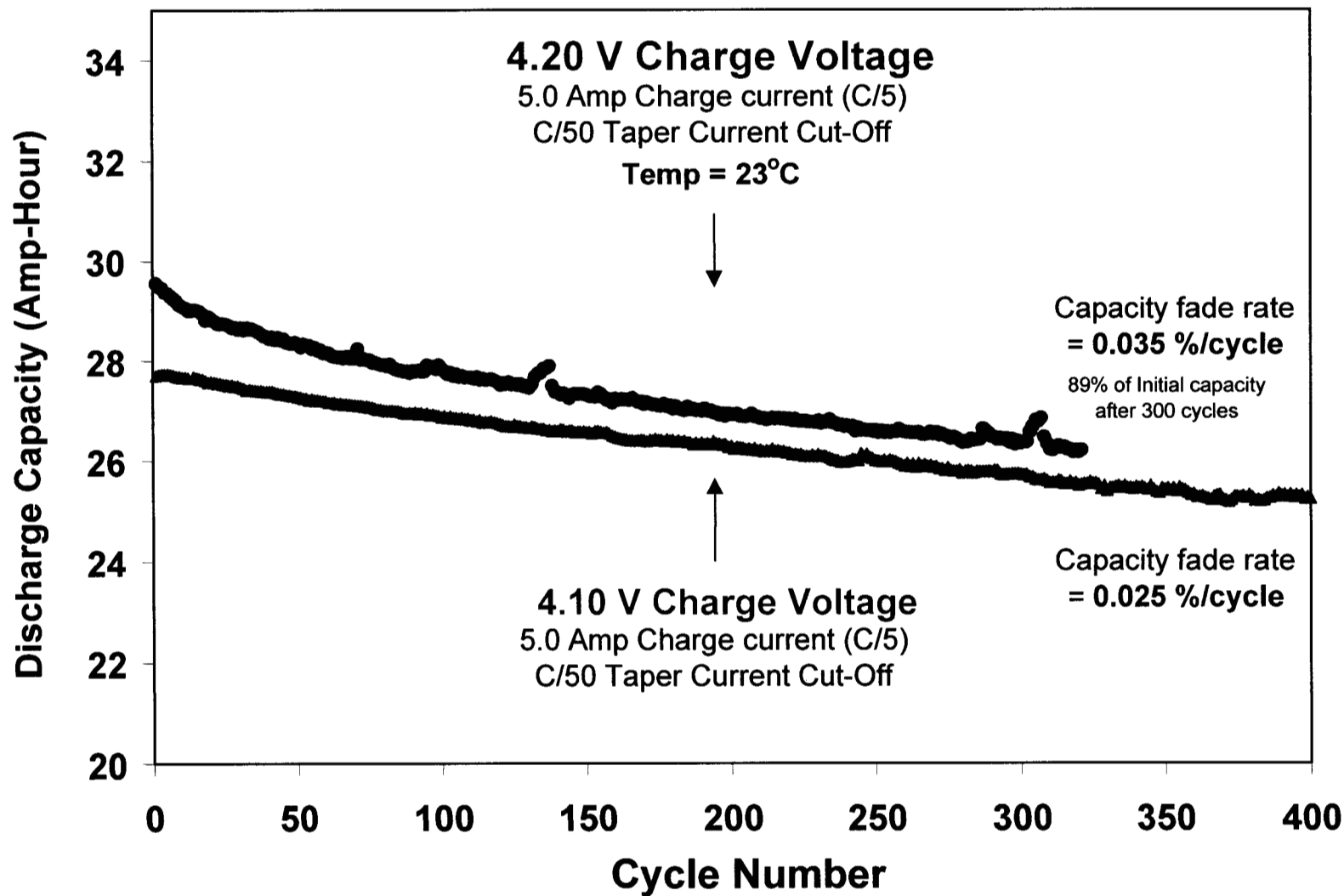


- Cells delivered > 1000 cycles at 100dod and RT
- Cells completed more than 700, 100% dod cycles at -20°C
- Observed similar performance capability in both 8 and 25Ah cells
- Cells from all vendors similar capabilities
- Cycling cells at low and high temperatures was found effect low temp performance



Lithium-Ion Cell Technology Assessment

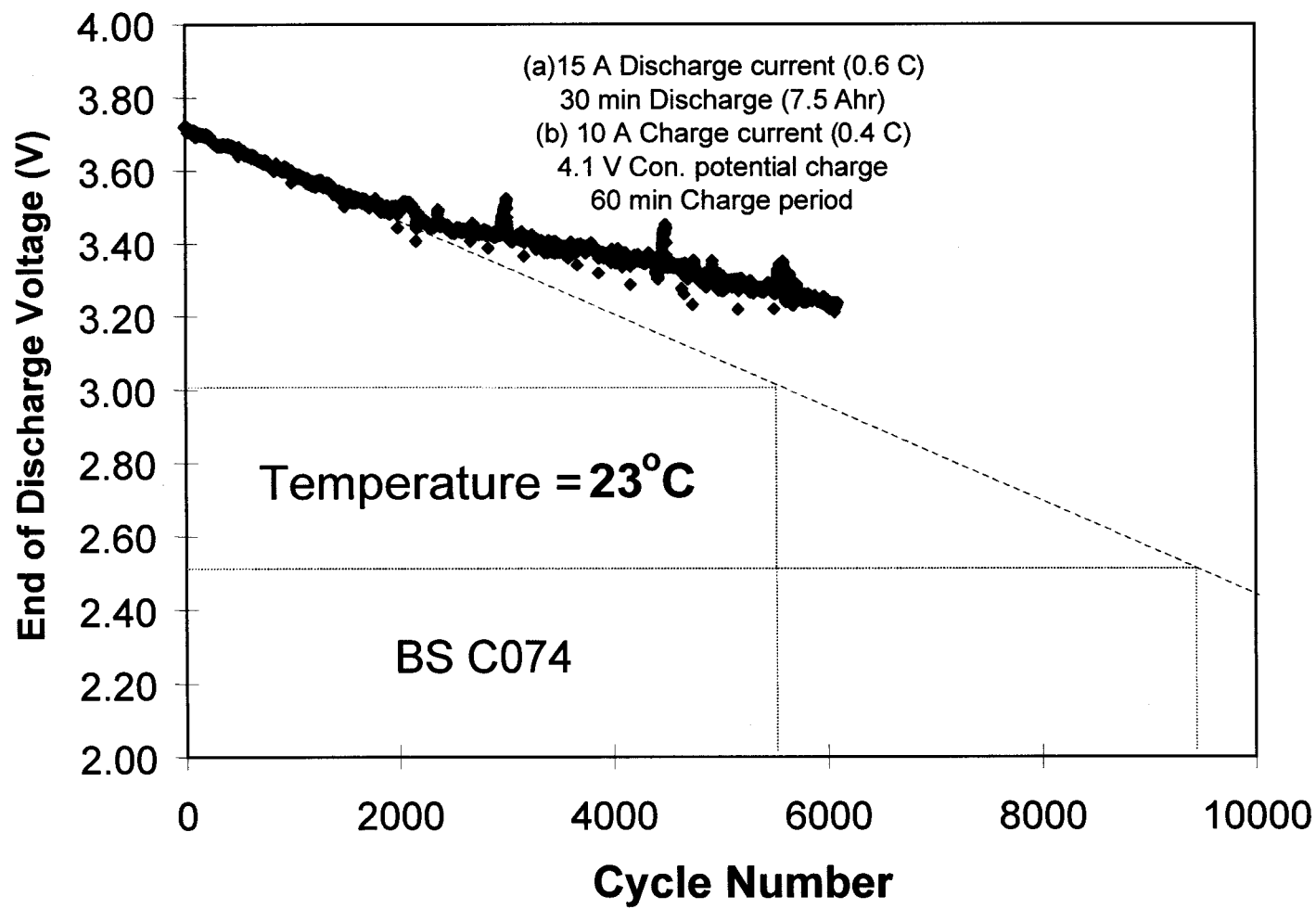
Effect of Charge Voltage Upon Cycle Life Characteristics





Lithium-Ion Cell Technology Assessment

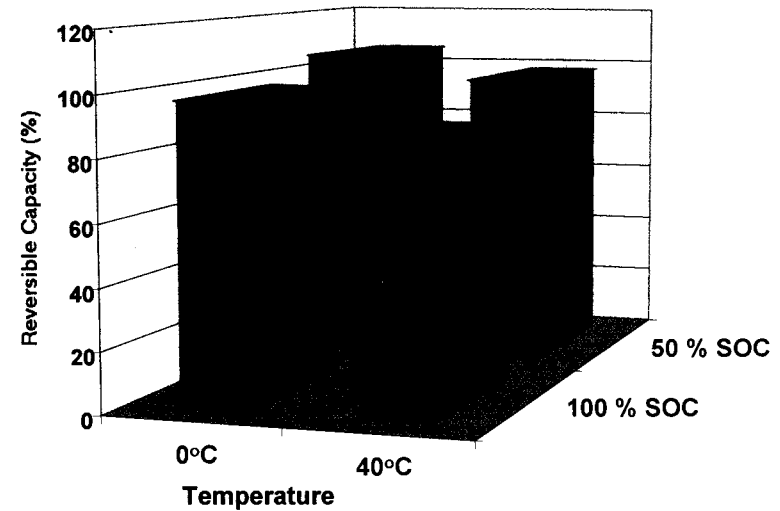
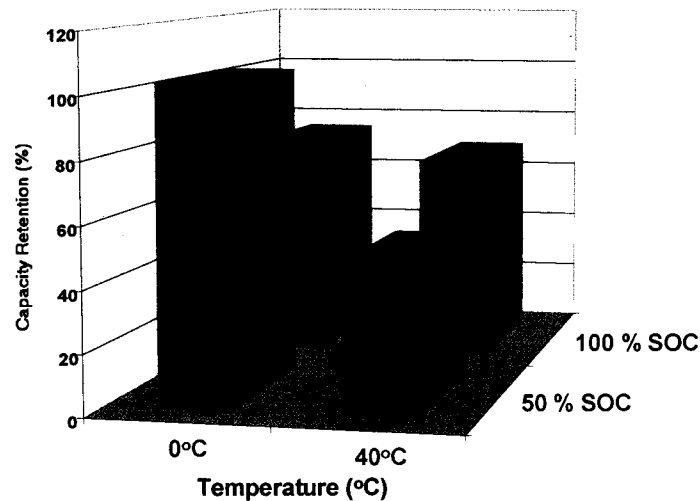
Leo Cycle Life Assessment Studies





Li-Ion Battery Technology Assessment

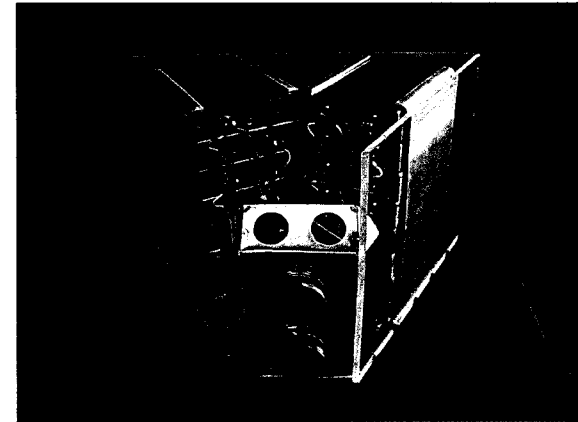
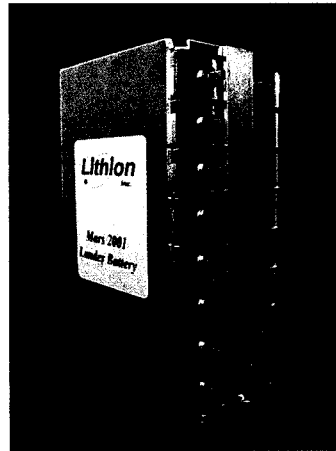
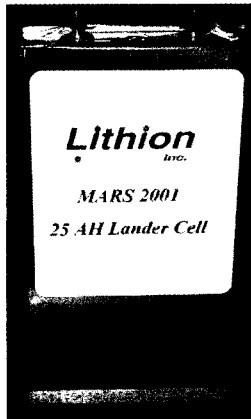
Effects of Storage Conditions



- Storage of cells at low temperatures was found to minimize self discharge
- Storage of cells at low temperatures was also found to minimize irreversible capacity losses on storage
- Storage of cells at lower stages of charge were found to minimize irreversible capacity losses on storage



Mars 01 Lander Battery Development Status



- **Launch environmental withstand ability**
- **10 month cruise storage capability**
- **Mars surface operational capability**
 - **Met EDL Performance Requirements**
 - **50 A Pulse operations at 0 C**
 - **60 simulated Sol operational capability at -20 to 40 C (testing continuing)**
- **Three year calendar life**



Summary and Conclusions



- ***Li Ion cells meet the Mars mission requirements in***
 - ***Cycle Life Performance***
 - Room Temperature = Excellent (>90% @ 200 cycles)
 - Low Temperature (-20) = Sufficient
 - High Temperature (40°C) = Sufficient (>70% @ 200 cycles)
 - ***Discharge Rate Capability at Various Temperatures***
 - Room Temperature = Excellent
 - Low Temperature (-20) = Sufficient (~ 24 Ah @ C/5 rate)
 - High Temperature (40°C) = Excellent
 - ***Storage Characteristics***
 - Demonstrated minimal reversible capacity loss (2 months)
 - Identified temperature as most crucial storage parameter
 - Demonstrated efficacy of storage “on the buss”
 - ***Mission simulation (Variable Temperature Cycling)***
 - Identified potential performance limiting conditions (worst case)
 - Implemented characterization test to quantify behavior